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CHARACTERISTICS OF THE TURBULENT DIFFUSION PARAMETERS AS RELATED TO STABILITY

Manuel Armendariz, et al

Army Electronics Command
White Sands Missile Range, New Mexico

November 1972

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By

Manuel Armendariz

James R. Scoggins

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13. ABSTRACT

The objective of this study was to demonstrate the extent to which a difference in temperature (ΔT) between two levels near the ground (static atmospheric stability) and the ratio z/L (dynamic atmospheric stability) is related to other parameters indicative of turbulence and diffusion. The data show, if we assume that the rate of diffusion is determined by the intensity of turbulence, that (ΔT) measured through a shallow layer near the ground is not a good indicator of diffusion rates, particularly when the atmosphere is statically unstable. The ratio z/L does not appear to be a significantly better indicator for defining atmospheric stability than (ΔT) during highly unstable conditions.

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INTRODUCTION

This study was undertaken at the request of the Selected Systems Effectiveness Program (SSEP) of the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME). The study is an effort to determine the effectiveness of present Department of Defense methodology in determining or predicting the diffusion of chemicals and/or radiological matter in the atmosphere. In particular, the study shows the extent to which a difference in temperature between two levels near the ground (static stability) or dynamic stability (ratio z/L) is related to the governing parameters of turbulence in the diffusion models considered.

DISCUSSION

Haugen and Fuquay [ ] pointed out that one should consider several meteorological parameters in characterizing the diffusive power of the atmosphere. Among these parameters are the following:

1. The mean wind velocity, determining the path of the cloud downwind from the source and the distribution of particles along the mean wind path. In the case of a continuous source this downwind transport results in a lower concentration of particles as the mean wind increases.

2. The RMS (standard deviation) of the wind direction (σ_A), determining the shape and distortion of the cloud, and in a sense serving as an indication of horizontal mixing.

3. The RMS (standard deviation) of the vertical wind direction (σ_E), determining the dispersion of the cloud in the vertical.

4. The vertical temperature gradient (ΔT) as an indicator of vertical mixing. If the temperature increases with height, the vertical mixing is limited to mechanical turbulence transport, whereas both mechanical and convective mixing generally occur during non-inversion conditions.

Relationships between the four parameters discussed above have been examined by Haugen and Fuquay [1] and Record et al. [2]. Models which quantitatively predict turbulent diffusion often assume that these relationships exist. In particular, the United States Army Combat Development Command's Field Manual 3-10, "Employment of Chemical and Biological Agents," utilizes a ΔT between heights of 0.5 and 4.0 meters to determine the horizontal and vertical rates of turbulent mixing. Various levels have been used for the measurement of the temperature gradient; e.g., project Ocean Breeze and Dry Gulch [1] used temperatures at heights of 2 and 17 meters. More recently, Record et al. [2] used heights of approximately 3 and 20 meters. The actual levels at which these temperature measurements were made were based primarily on existing instrumentation at the site. Because of the highly varying conditions observed near the surface, there is a need to investigate the effects of choice of heights on turbulent diffusion parameters.

SOME FUNDAMENTAL CONCEPTS

A. Wind and Its Variability

Wind is initiated by pressure forces which are created by density gradients resulting from differential heating. It is modified by the rotation of the earth, frictional effects, and by centrifugal forces due to the curvature of the air trajectory. In the surface boundary layer curvature and coriolis effects often may be neglected. The speed and direction of the wind then depends primarily on the magnitude and direction of the pressure gradient force, and on the properties of the surface which determine the magnitude of the frictional force.

The influence of friction decreases with altitude and may vary with horizontal distance. When the surface is rough, the wind speed increases rapidly at heights just a few meters above the ground and less rapidly at greater heights. When the ground is smooth, the increase of wind speed with height is less pronounced but is still greater in the lowest few meters. Mechanical turbulence created by roughness elements decreases with height more rapidly over a rough surface than a smooth surface. When the degree of surface roughness changes horizontally, changes in wind and the intensity of turbulence at a given height result. Surface features such as hillocks, vegetation, and changes in other terrain features such as soil composition (which may lead to differential heating and variations in the pressure gradient force) induce spatial variations in wind speed and turbulence.

At present, it is not possible to determine analytically the micro- and mesoscale forces in space and time which affect the wind. It is possible, however, to determine the average magnitude of the forces in space, and hence the average wind may be determined with reasonable accuracy. Variations in the wind in both space and time within local areas are usually determined statistically, leaving much to be desired in terms of accuracy. It is this variability in wind which leads to extreme complexities in problems of diffusion and transport of airborne substances, impact predictions of unguided rockets, and numerous and varied meteorological problems, such as heat and momentum transfer and the coupling actions between layers of the atmosphere with differing wind speeds and stability.

B. Definition of Turbulence

The vector wind can be written as

$$\vec{V} = \vec{\overline{V}} + \vec{v}' \qquad (1)$$

where the bar denotes an average value, an arrow a vector quantity (the absence of an arrow denotes a scalar quantity), and the prime a deviation from the average. Equation (1) may be written in component form as

$$u = \overline{u} + u'$$

$$v = \overline{v} + v' \qquad (2)$$

$$w = \overline{w} + w'$$

where u, v, and w refer to the components of the wind along the orthogonal axes x, y, and z, respectively. Deviations from the average are referred to as turbulence and represent that portion of the wind which must be treated statistically. The average may or may not be a function of time. A hypothetical time trace of wind speed showing $\overline{u}$ and u' at a given location near the ground is illustrated in Figure 1. The variations in speed are caused by variations in the forces discussed above.

C. Factors Responsible for Turbulence

A convenient way of looking at the rate of growth and decay of turbulent energy is to examine the terms in the eddy kinetic energy equation. Lumley and Panofsky [3] wrote this equation in the simplified form

$$\underset{(A)}{\frac{D(\overline{KE'})}{Dt}} = \underset{(B)}{\overline{\rho} K_m \left(\left| \frac{\partial \overline{\vec{V}}}{\partial z} \right| \right)^2} - \underset{(C)}{K_H \frac{\overline{\rho} g}{\overline{\theta}} \frac{\partial \overline{\theta}}{\partial z}} - \underset{(D)}{\varepsilon} \qquad (3)$$

Here $(\overline{KE'})$ is the average kinetic energy of the three components of turbulence, K_H and K_m are the eddy exchange coefficients for heat and momentum, respectively, $\overline{\theta}$ is an average potential temperature in degrees Kelvin, $\overline{\rho}$ is an average density, g is gravity, $\overline{\vec{V}}$ is the mean wind velocity, z is height, and ε represents the dissipation of mechanical energy into heat. The terms comprising this equation are interpreted as follows:

1. Term (A) represents the time-rate-of-change of the average turbulent energy following the mean motion. Under equilibrium conditions and neglecting any advective processes, this term will be zero. A positive value of term (A) represents the growth and a negative value the decay of turbulent energy.

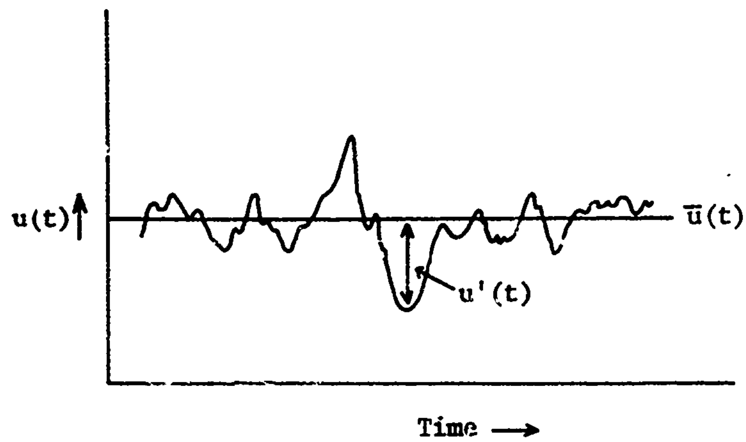

Figure 1. TIME TRACE OF WIND SPEED SHOWING $\overline{u}(t)$, u(t), AND u'(t).

2. Term (B) represents the work done by the turbulent stresses against the rates of mean strain. This term is usually positive and thus contributes to the growth of turbulent energy.

3. Term (C) represents the work done against buoyancy. This term can be an energy source or sink depending on the gradient of potential temperature, and it may be negligible when the gradient vanishes.

4. Term (D) represents the rate of dissipation of turbulent kinetic energy. Since dissipation is always a positive quantity, the negative sign makes the entire term an energy sink.

Richardson (see Sutton [4]) postulated that the state of turbulence can be determined from the ratio of term C to term B in Eq. (3), viz.,

$$Rf = \frac{K_H}{K_M} \frac{g}{\theta} \frac{\partial\overline{\theta}/\partial z}{(|\partial\vec{\overline{V}}/\partial z|)^2} \tag{4}$$

Rf is referred to as the flux Richardson number. If it is assumed that $K_H/K_m = 1$, then Eq. (4) becomes the gradient Richardson number, Ri. If Rf = 1, then the buoyancy forces remove turbulent energy at the same rate that it is being produced by the shearing stresses. This does not mean that Rf = 1 is a critical value for predicting the onset of turbulent motion but rather the condition for equilibrium. It is clear, however, that Rf < 1 indicates turbulent energy growth and Rf > 1 indicates decay.

It is also possible to express Rf as a function of height in non-dimensional form using similarity theory [3]. A non-dimensional wind shear, S, can be defined as

$$S \equiv \frac{kz}{u^*} \frac{\partial\overline{V}}{\partial z} \tag{5}$$

where k is von Karman's constant, u* is the friction velocity, and the other variables are as previously defined. A scaling length, L, defined by Monin and Obukhov (see Lumley and Panofsky [3]), is given by

$$L \equiv - \frac{C_p\rho\overline{\theta}u^{*3}}{kgH} \tag{6}$$

where C_p is the specific heat of air at constant pressure, and H is the vertical flux of heat. Using Eqs. (4), (5), and (6) and the following expressions for H and K_m:

$$H \equiv - \rho C_p K_H \frac{\partial \overline{\theta}}{\partial z} \tag{7}$$

$$K_m \equiv u^{*2} / \frac{\partial v}{\partial z}$$

we arrive at

$$SRf = \frac{-gHkz}{C_p \overline{\rho} \overline{\theta} u^{*3}} = z/L \tag{8}$$

Observation has shown [3] that in near-neutral conditions $S \doteq 1$ so that $Rf \doteq z/L$. Hence, z/L is a measure of dynamic stability and thereby is a means of ascertaining whether or not there is a growth or decay of turbulent kinetic energy.

D. Diffusion Theory

The intensity of turbulence, I, is given by Slade [5] as

$$I_x = \frac{\sigma_u}{\overline{V}}; \; I_y = \frac{\sigma_v}{\overline{V}}; \; I_z = \frac{\sigma_w}{\overline{V}} \tag{9}$$

where the σ's represent the standard deviation of the longitudinal (u), lateral (v), and vertical (w) components of turbulence, $\overline{V}$ is the average wind speed, and x, y, and z refer to coordinate directions. Longitudinal refers to the direction along the mean wind, and lateral to the perpendicular to the mean wind direction. The diffusing power of the atmosphere is directly related to the I's. When the average wind direction is along the x-axis such that $\overline{v} = 0$, then there is no y component and we can write

$$\sigma_A = \frac{\sigma_v}{\overline{V}} \quad \text{and} \quad \sigma_\Phi = \frac{\sigma_w}{\overline{V}} \tag{10}$$

where A is wind direction (azimuth) in radians, and σ_Φ is the standard deviation of the inclination of the vector wind in radians (when $\Phi = 0$, the wind is horizontal). In practical diffusion work the basic problem is to relate the measurable quantities given in Eqs. (9) and (10) to the dispersion of airborne effluents under various stability conditions.

Statistical theories of turbulent diffusion show that the variance of particle diffusion in the y-direction under different conditions is given by [6]

$$\overline{y^2(t)} = 2Kt \quad (t \text{ large}) \tag{11}$$

$$\overline{y^2(t)} = \overline{v'^2}\, t^2 \quad (t \text{ small}) \tag{12}$$

and

$$\overline{y^2(t)} = 1/2\, C_y^2\, \overline{(ut)}^{2-n} \quad (t \text{ intermediate}) \tag{13}$$

where Gaussian distribution of the particles has been assumed, and where

$y(t)$ = cross wind distance that a particle moves from some origin

K - eddy diffusion coefficient

t = time

C_y = eddy diffusion parameter in the y-direction

n = stability parameter

v' = crosswind turbulent fluctuation

u = mean wind speed

The constant K in Eq. (11) and C_y in Eq. (13) depend upon the intensity of turbulence as given in Eqs. (9) and (10). While it will not be shown here, the value of $\overline{y^2(t)}$ in Eq. (12) depends on the total spectrum of the turbulence. In Eq. (13), D_y^2 is a function of the average wind speed, the variance of the lateral velocity fluctuations, and stability. The influence of stability is contained in the parameter n defined from the wind profile by the relation

$$\frac{\overline{V}_1}{\overline{V}_2} = \left(\frac{z_1}{z_2}\right)^{\frac{n}{(2-n)}} \tag{14}$$

where $\overline{V}_1$ is measured at z_1 and $\overline{V}_2$ at z_2. Different values of n represent different stability conditions. Thus, the value of $\overline{y^2}$ in Eqs. (11) - (13), which determines the distribution of particles in the cross-wind direction (along the y-axis), is related to the intensity of turbulence given by Eq. (9), the total energy spectrum of turbulence, variability of wind direction (Eq. (10)), stability, and average wind speed. As discussed previously, these variables are interrelated with each one usually expressed as a function of stability. Thus, the rate of diffusion is related to the degree of stability.

E. Meteorological Variables Related to Diffusion Parameters

The meteorological variables most commonly related to atmospheric diffusion near the ground include: 1) the intensity of turbulence, 2) the spectrum of turbulence, 3) variability of wind direction (vertical and horizontal), 4) stability, and 5) wind speed. These parameters are related in some way to K and C_y in Eqs. (11) and (13), or to the production terms in the kinetic energy equation for turbulence (Eq. (3)). Static stability and wind speed near the ground are related through Eq. (14). To illustrate the relationship between stability and the diffusion coefficients, the following data were taken from page 243 of Atmospheric Diffusion by Pasquill [7].

TABLE I. DIFFUSION PARAMETERS VS. ATMOSPHERIC STABILITY

Stability	$T_{183\ ft} - T_{5\ ft}$ (°F)	n	C_y ($m^{n/2}$)
Neutral	-1 and 0	0.25	0.095-0.14
Moderate inversion	+1 to +5	0.33	0.052-0.077
Strong Inversion	6	0.50	0.029-0.074

The diffusion coefficient in the lateral direction, C_y, is assumed to equal that in the vertical direction. Static stability is a function of wind speed, terrain conditions, the type of air mass present, cloudiness (or radiation), and other parameters. It is observed that the concentration of pollutants increases over cities during stable conditions while rapid dispersion takes place during unstable conditions. While the magnitude of the diffusion coefficient is proportional to instability, the relationship between the concentration of pollutants and stability conditions does not always exist. For example, mechanical turbulence may exist even during inversion conditions, which leads to an increase in C_y. A wide range of values for the diffusion coefficients under different atmospheric conditions are summarized by Pasquill [7] and Gifford [6]. A rather wide range of values has been obtained from experimental results.

DATA

The data utilized in this study were obtained from instruments set up in an array forming a "T" over distances of 300 meters. The instruments utilized were R. M. Young Company's UVW (propeller anemometers) along with unaspirated thin wire thermocouples. The accuracies of these instruments and data, spacing of poles on which instruments were mounted, and terrain characteristics have been described by Armendariz et al. [8]. Briefly, the area is composed of hillocks 2 to 3 meters in height and randomly spaced approximately 5 to 10 meters apart. The distance constant of the wind instruments is 1.3 meters and data were automatically collected at a rate of one sample per second. The thermocouples, 0.0025 cm in diameter and made of copper constantan, have a time constant less than 0.5 seconds Wind instruments were placed at 1.5 and 4.0, or 4.0 and 16.0 meters in height on alternate poles in the array. Temperature differences were recorded between 0.5 and 4.0 meters and between 4.0 and 16.0 meters. Data were collected during the months of January, February, and March of 1970. In general, the collection of data was made over two-hour periods during both day and night. There were some periods of continuous data collection lasting six or seven hours.

OBSERVED RELATIONSHIPS BETWEEN STATIC STABILITY AND SELECTED DIFFUSION PARAMETERS

Relationships between meteorological variables such as static stability, variations in wind direction, wind speed, etc., and atmospheric diffusion parameters are complicated even in relatively simple situations, and cannot be specified with confidence in complex situations. The analysis of the T-array data presented here is aimed at illustrating some of the complexities involved as well as some of the relationships between static stability represented as the difference in temperature between two heights and certain parameters associated with atmospheric diffusion. The objective is to demonstrate, for the period of study chosen, the extent to which a difference in temperature between two levels near the ground and the ratio z/L are related to other parameters indicative of turbulence and diffusion.

A. Intensity of Turbulence

1. Longitudinal -- The longitudinal intensity of turbulence is represented by σ_u, which is the standard deviation of the fluctuation along the mean wind flow. The relationships between z/L, ΔT, and σ_u for selected heights are shown in Figure 2. The difference in temperature between the indicated heights in each figure is shown on the ordinate, σ_u on the abscissa, while z/L is the third variable plotted in each figure. Isopleths are drawn for values of z/L, and a line was drawn by eye to represent the relationship between ΔT and σ_u.

In Figure 2a, σ_u is a function of ΔT but the relationship is not linear. It can be seen that σ_u initially increases as ΔT decreases, but then decreases as ΔT decreases further. The ratio z/L decreases as ΔT decreases, but the decrease is not regular when z/L becomes less than approximately -0.02. In Figure 2a neither ΔT nor z/L is a good indicator of σ_u, which as we recall from the theory presented in Section II is directly related to the diffusive power of the atmosphere for a given mean wind speed. Figure 2b differs from Figure 2a only in that z/L and σ_u are computed at a height of 4 meters rather than 1.5 meters. The results are similar and show some indication of a slight increase in σ_u with a decrease in ΔT. As in Figure 2a, there is a poor relationship between z/L and σ_u when z/L becomes negative (less than -0.05).

In Figure 2c, where ΔT is determined between 4 and 16 meters, and z/L and σ_u at 4 meters, σ_u is related to ΔT except when ΔT is large and negative. The ratio z/L decreases as ΔT decreases and σ_u increases except at large negative ΔT. When ΔT reaches values of -0.5 and less it no longer indicates the level of turbulence. In this range, z/L increases as σ_u increases. When ΔT exceeds -0.3, both ΔT and z/L are related to σ_u.

The fact that relationships between the parameters considered here change drastically at different levels in the atmosphere is illustrated in Figure 2d. This figure is similar to Figure 2c with the only change being that z/L and σ_u are determined at 16 meters rather than at 4 meters. In Figure 2d, σ_u increases as ΔT decreases, but for any ΔT, σ_u may vary from approximately 1.5 to 3 mps. The relationship between ΔT and σ_u is quite weak. z/L and ΔT show a similar relationship to σ_u.

2. Lateral -- In Figure 3 the lateral intensity of turbulence, σ_v, is shown as a function of z/L and ΔT for the same data as in Figure 2. The relationships between the variables in Figure 3a are the same as those discussed above for Figure 2a. By comparison, Figure 3b differs considerably from its counterpart, Figure 2b. Here, σ_v decreases with decreasing ΔT when ΔT<-0.5. As ΔT becomes smaller, σ_v varies by a factor

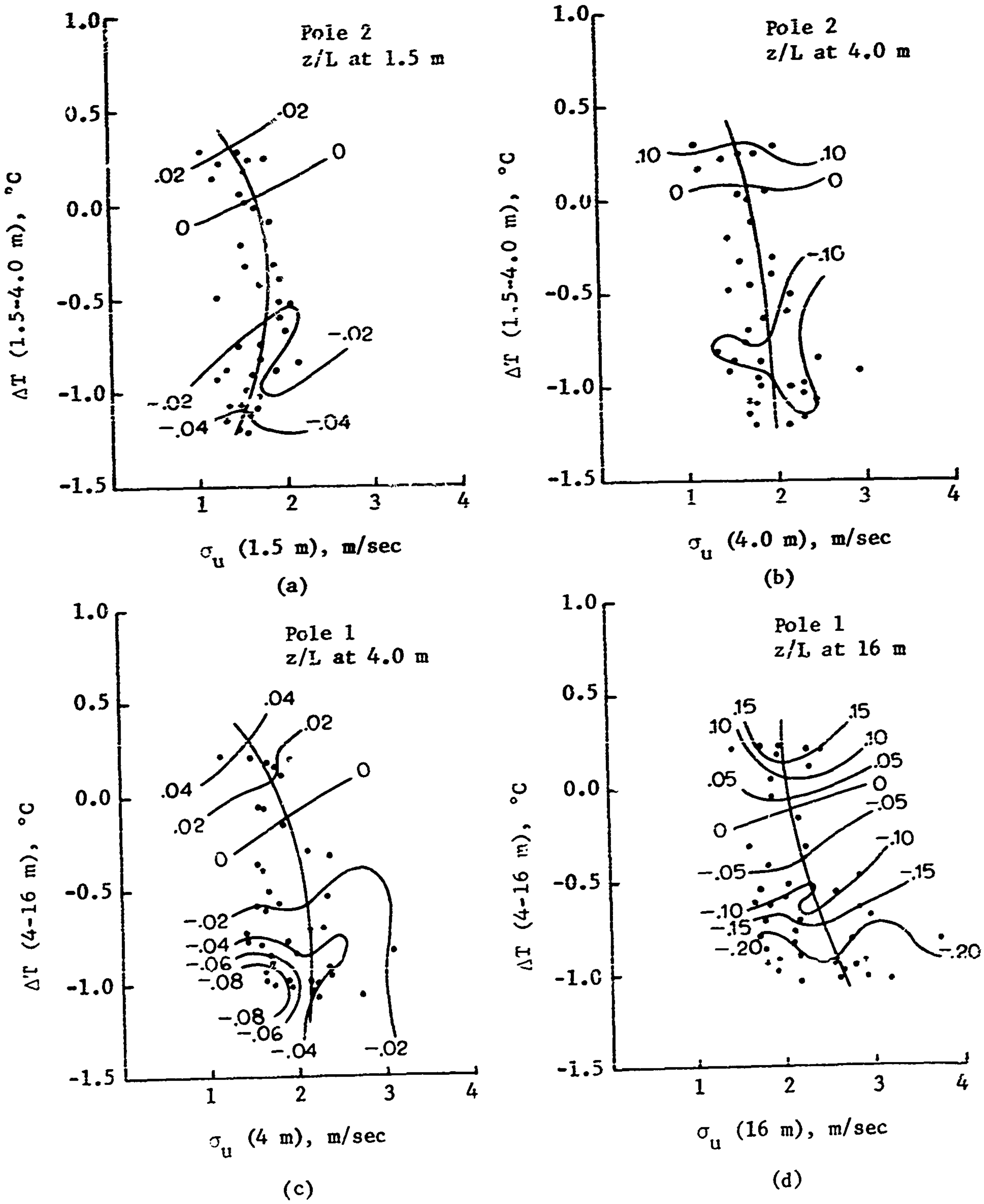

Figure 2. GRAPHICAL RELATIONSHIPS BETWEEN ΔT, σ_u, AND z/L.

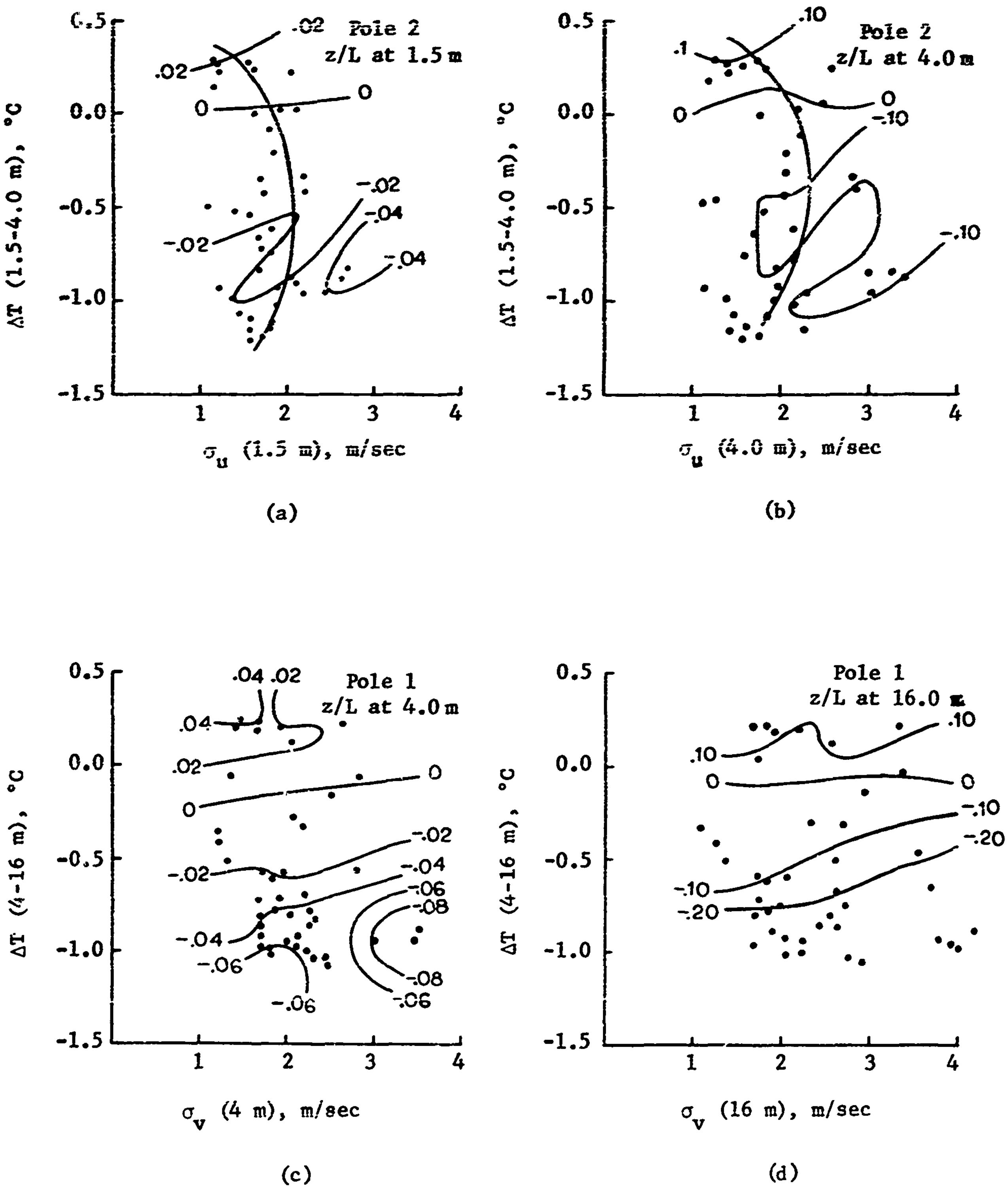

Figure 3. GRAPHICAL RELATIONSHIPS BETWEEN ΔT, σ_v, AND z/L.

of 2-3 for a given value of ΔT. Except for near-neutral conditions, z/L is not a good indicator of σ_v and when z/L<-0.1, the relationship between z/L and σ_v apparently has vanished.

In Figure 3c, ΔT is not related to σ_v. σ_v varies from approximately 1.5 to 3.5 for any value of ΔT. The ratio z/L also is not related to σ_v any better than to ΔT. These rather poor relationships extend to Figure 3d, which shows that σ_v is not related to ΔT and that σ_v varies between 1 and 4 mps for any given value of ΔT. In addition, there is no apparent relationship between z/L and σ_v.

3. Vertical -- Relationships between z/L, ΔT, and σ_w are shown in Figure 4. Conditions represented in this figure are similar to those in Figures 2 and 3. In Figure 4a, σ_w is a function of $\Delta T>0$. When ΔT is less than this value, σ_w does not depend upon ΔT. The intensity of the vertical component of turbulence, σ_w, increases as z/L decreases to values near -0.02, but below this value z/L and σ_w are essentially constant. Figure 4b is similar to Figure 4a and shows that σ_w increases with a decrease in $\Delta T>-0.4$, and decreases for smaller values of ΔT. In this figure, z/L is a poor indicator of σ_w for all values.

Figure 4c is somewhat similar to Figures 4a and b and shows σ_w to be related to ΔT, but the relationship is not linear. σ_w increases as ΔT decreases to values above about -0.3, but as ΔT becomes smaller σ_w remains essentially constant, with some slight tendency to decrease as ΔT approaches -1.0. The ratio z/L decreases with an increase in σ_w for all ΔT except for ΔT <-0.8, in which case larger negative values of z/L are associated with smaller values of σ_w.

Figure 4d differs from Figures 4a-c in that σ_w increases as ΔT decreases throughout the entire range of ΔT. In addition, z/L decreases as σ_w increases and ΔT decreases. In this figure, both ΔT and z/L are related to σ_w in a reasonably definite way.

B. Variability of Wind Direction

The variability of wind direction is considered in Figure 5. The conditions in this figure are similar to those in Figures 2-4 except that the standard deviation of component wind speeds has been replaced by σ_A. As we can see from Eq. (10), σ_A is a measure of the intensity of turbulence for a given mean wind speed. In Figure 5a, σ_A is not related to ΔT; in addition, z/L is not related to σ_A in any definite way. When z/L <-0.02, σ_A may vary by a factor of about 4 while z/L remains essentially constant. Similar relationships are observed in Figure 5b except that when z/L becomes <-0.1, larger values of σ_A are associated with smaller values of z/L.

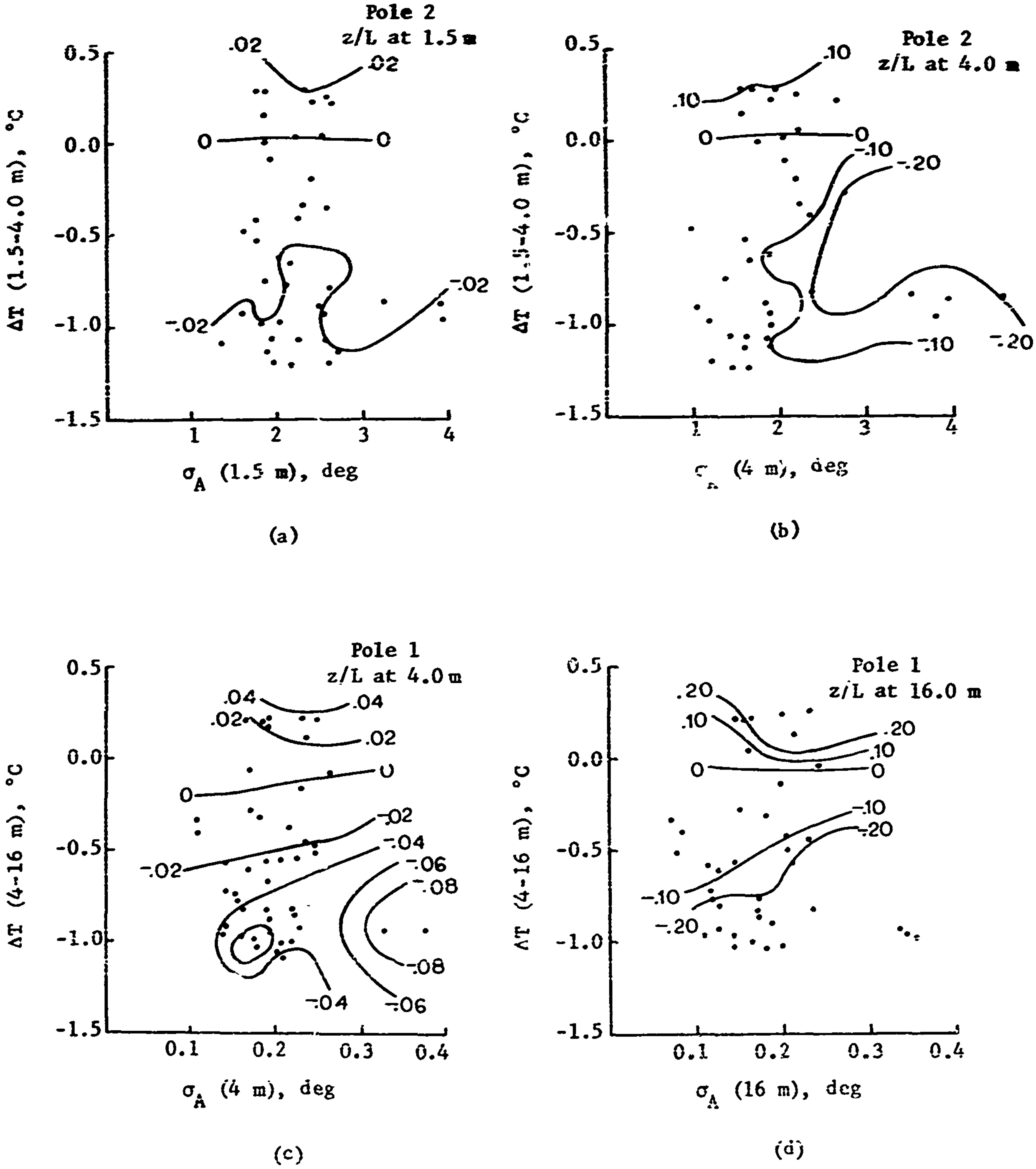

Figure 5. GRAPHICAL RELATIONSHIPS BETWEEN ΔT, σ_A, AND z/L.

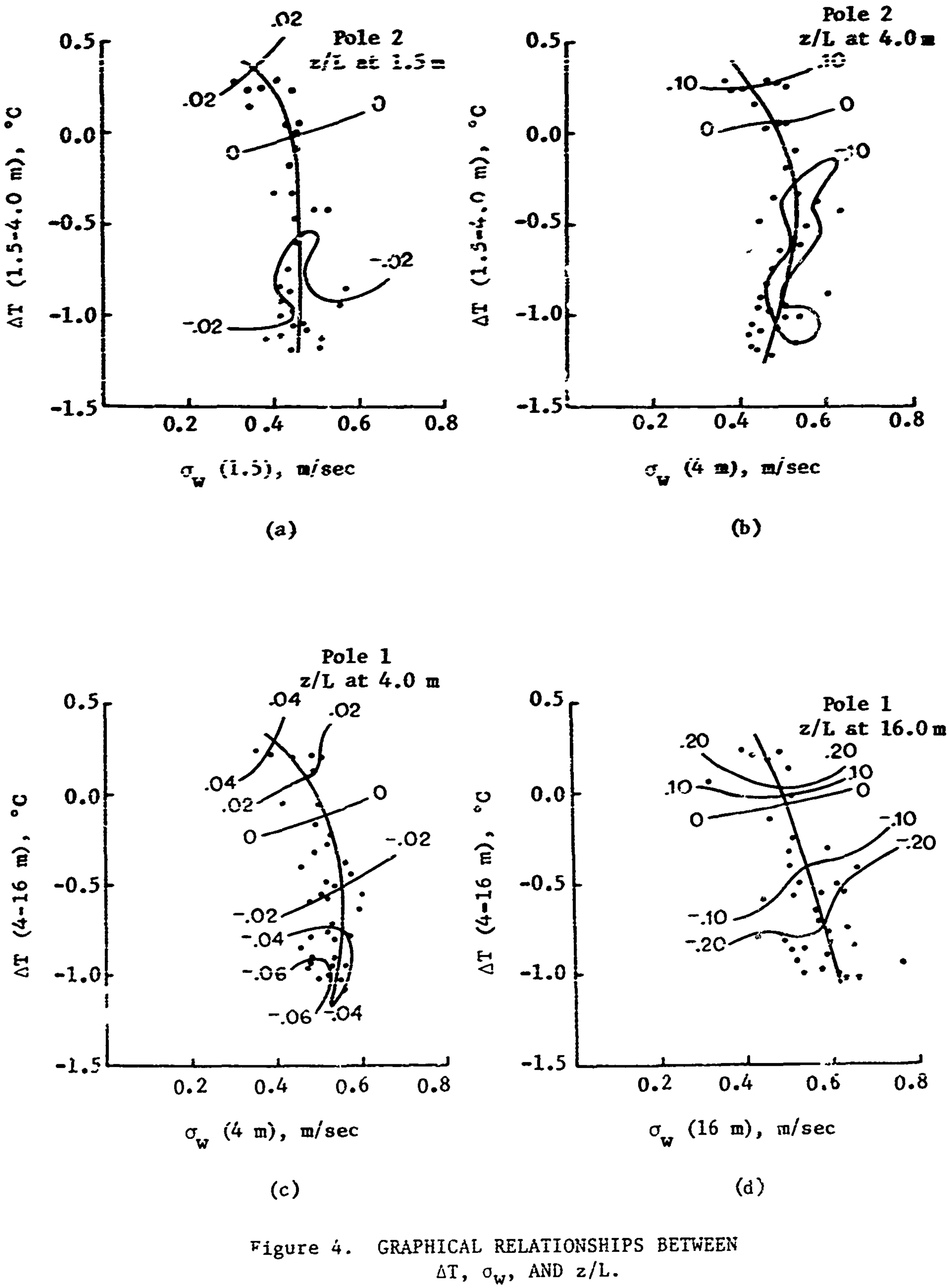

Figure 4. GRAPHICAL RELATIONSHIPS BETWEEN ΔT, σ_w, AND z/L.

Figure 5c is similar to Figure 5b. Again, σ_A is not a function of ΔT and is a function of z/L only when z/L <-0.04, which corresponds to a ΔT of approximately -0.8C. For z/L <-0.04, σ_A increases as z/L decreases. Thus, ΔT is not a good indicator of σ_A, while z/L is valid only at values $\leq$0.04. Similar relationships are observed in Figure 5d except that when z/L approaches -0.1, σ_A tends to increase as z/L decreases.

Figures 6a and 6b show σ_A at 1.5 meters versus ΔT between 0.5 and 4.0 meters and 1.5 and 4.0 meters for the period January-March 1970. Figure 6a differs considerably from Figure 6b with the difference due entirely to a slight change in the layer over which ΔT was measured. In excess of 150 hours of data are plotted in each part of these figures with each point representing a 15-minute average value. This larger sample of data agrees in general with the results from the much smaller sample considered in Figure 5. The major difference is that the range of σ_A for a given ΔT is much larger in Figures 6a and 6b than in Figure 5. Record et al. [2] found σ_A to vary with wind speed during stable and unstable conditions; however, this relationship was not examined.

From the above discussion it is evident that z/L and ΔT are somewhat related. Of course, they should be since ΔT appears in the Richardson number (Ri) and z/L = Ri for near-neutral conditions. The experimental relationship is shown in Figure 7 for the period January-March 1970. The relationship is quite poor. The scatter when $|z/L|$ and $|\Delta T|$ are large suggests that, at most, one or possibly neither of these parameters can be used as an indicator of the level of turbulence. In principle, z/L should be the better indicator; however, some refinements in its computation may be necessary when atmospheric conditions vary greatly from neutral.

C. Wind Speed

The relationships between the longitudinal ($\overline{u}$) and lateral ($\overline{v}$) component wind speeds at 1.5 meters, and T between 0.5 - 4.0 and 1.5 - 4.0 meters, are shown in Figures 8a and 8b for the period January-March 1970. For both wind components, the average wind speed increases as ΔT decreases for $\Delta T > 0$. When $\Delta T < 0$, the functional dependence disappears. A line has been drawn by eye through the points on each part of the figure when $\Delta T > 0$. The range in wind speed for a given ΔT is large, particularly for the lateral component, but there is little doubt that a trend is present in the data when ΔT is positive.

CONCLUSIONS

A. For the Layer 1.5 - 4.0 Meters

The standard deviations of all three components of the wind vector at 1.5 and 4.0 meters (σ_u, σ_v, σ_w) generally increase with a decrease in ΔT

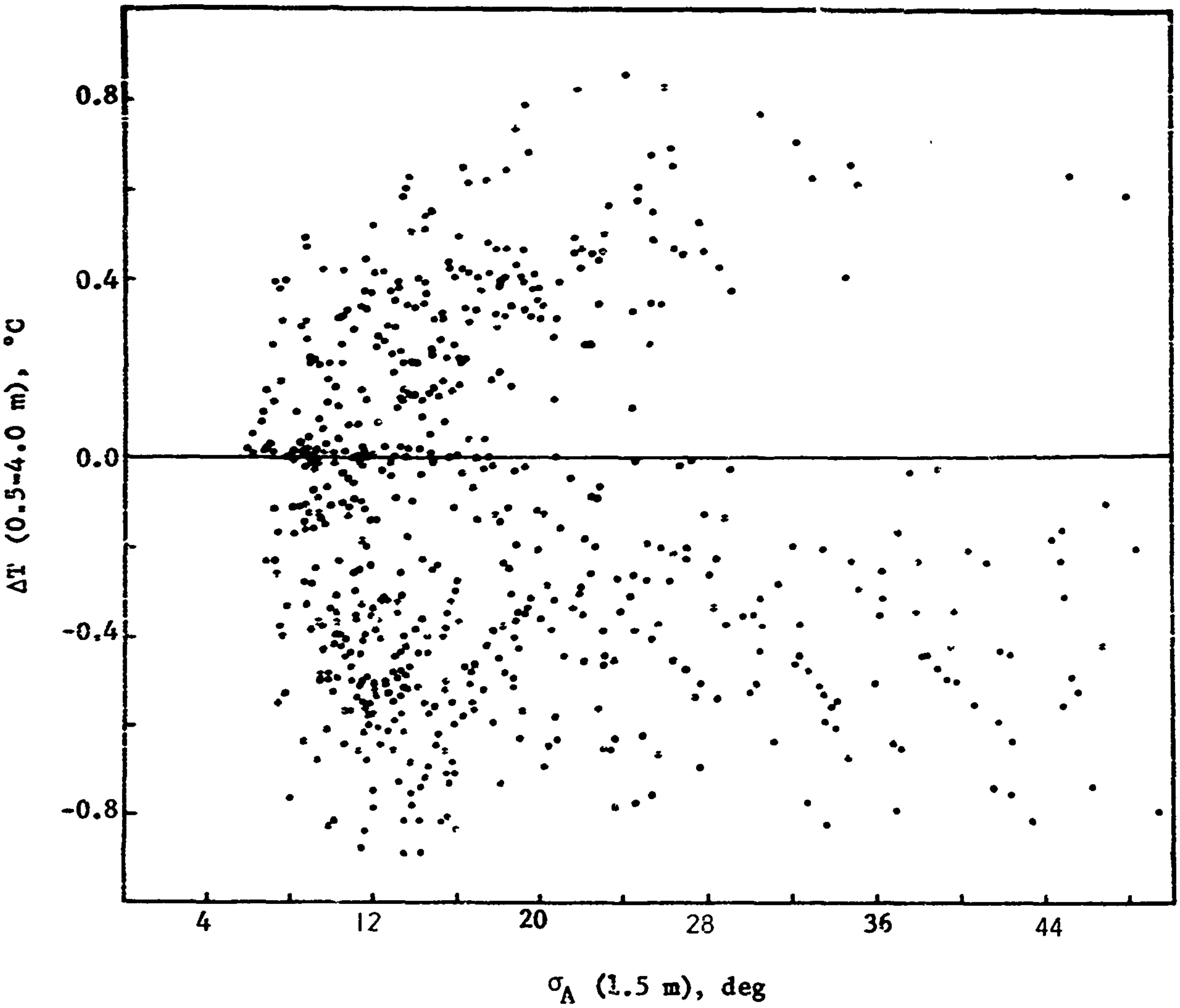

Figure 6(a). GRAPHICAL RELATIONSHIPS BETWEEN $\Delta T(0.5\text{-}4.0\ m)$ AND σ_A.

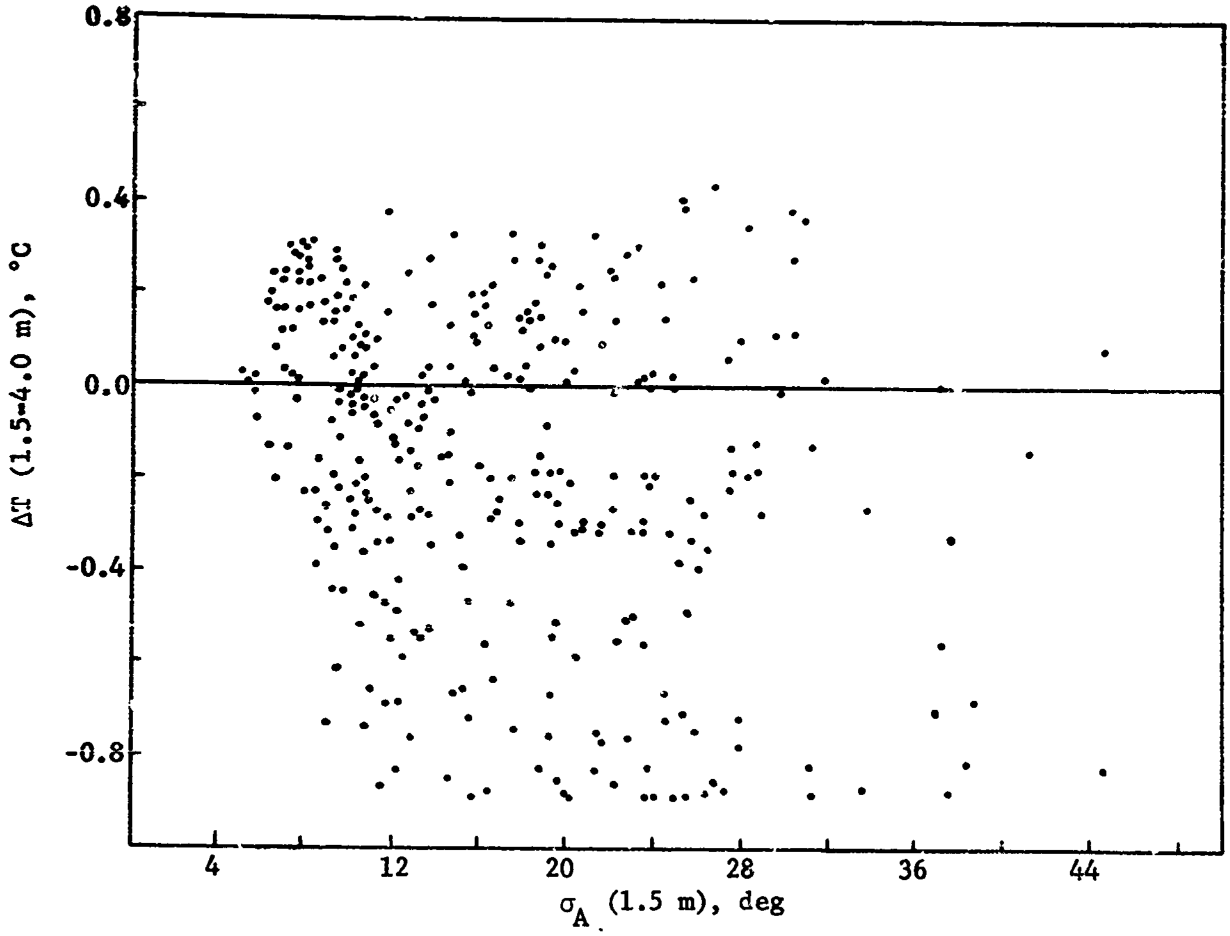

Figure 6(b). GRAPHICAL RELATIONSHIPS BETWEEN ΔT(1.5-4.0 m) AND σ_A.

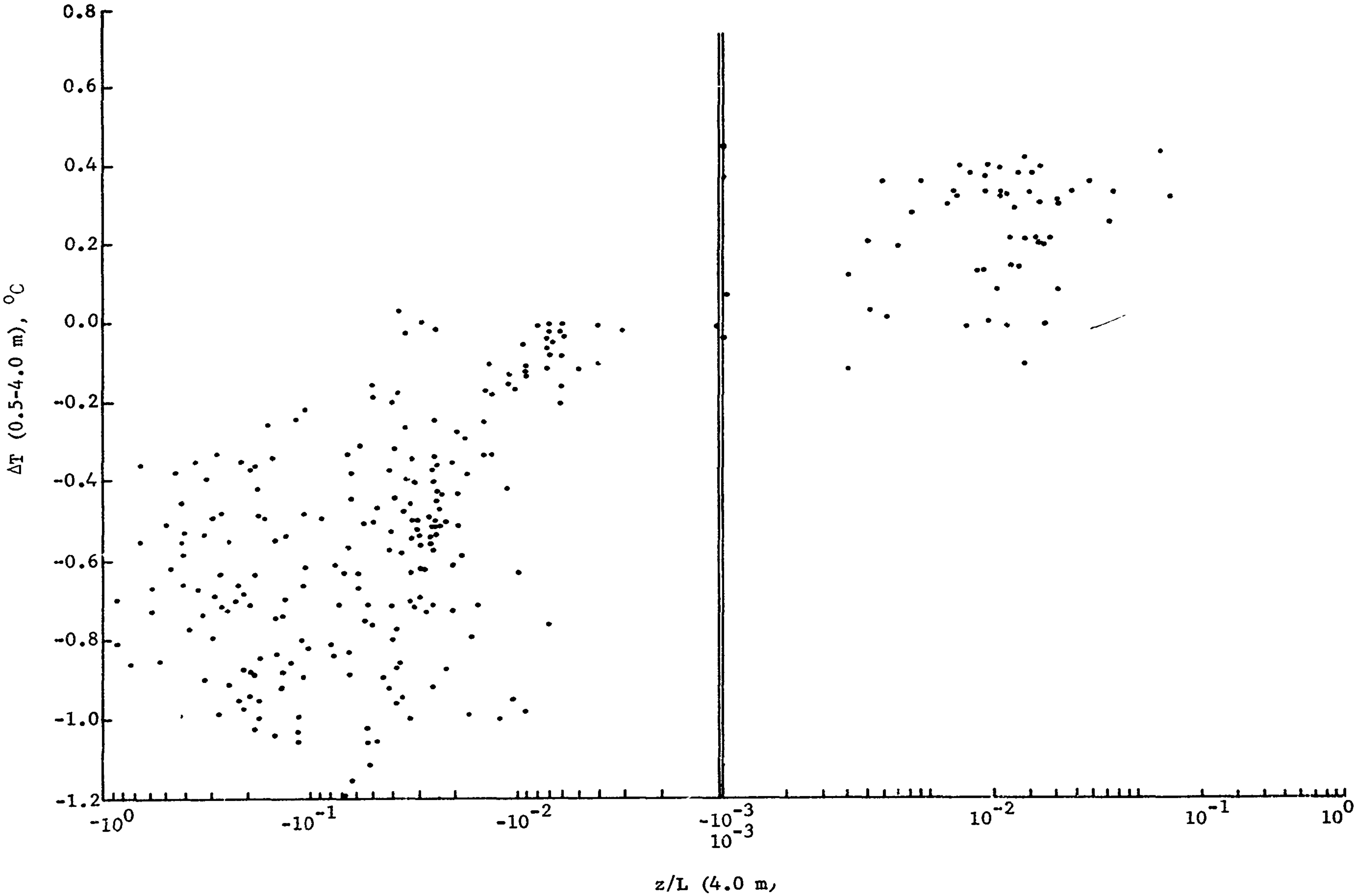

Figure 7. GRAPHICAL RELATIONSHIP BETWEEN ΔT AND z/L.
(THE DOUBLE LINE INDICATES A BREAK IN THE ABSCISSA.)

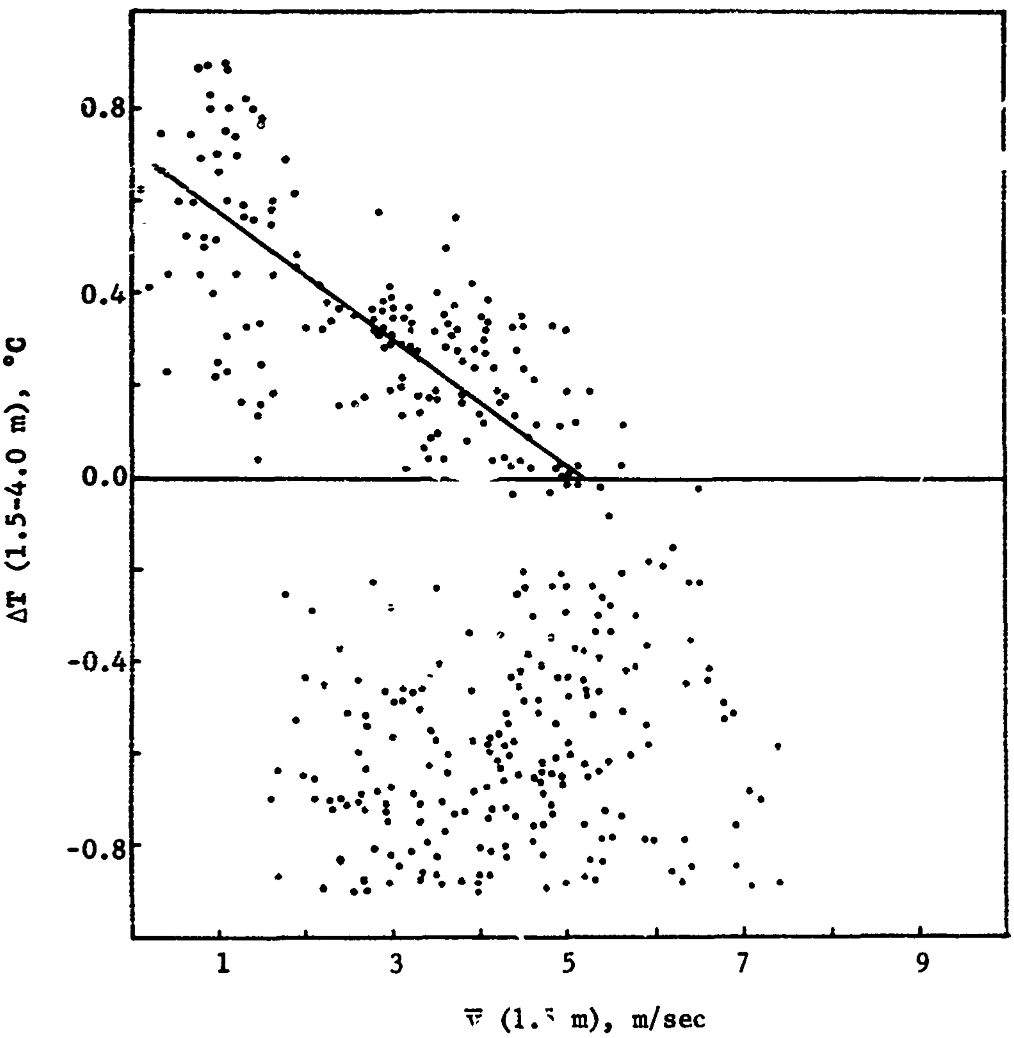

Figure 8(b). GRAPHICAL RELATIONSHIPS BETWEEN ΔT AND V̄(1.5 m).

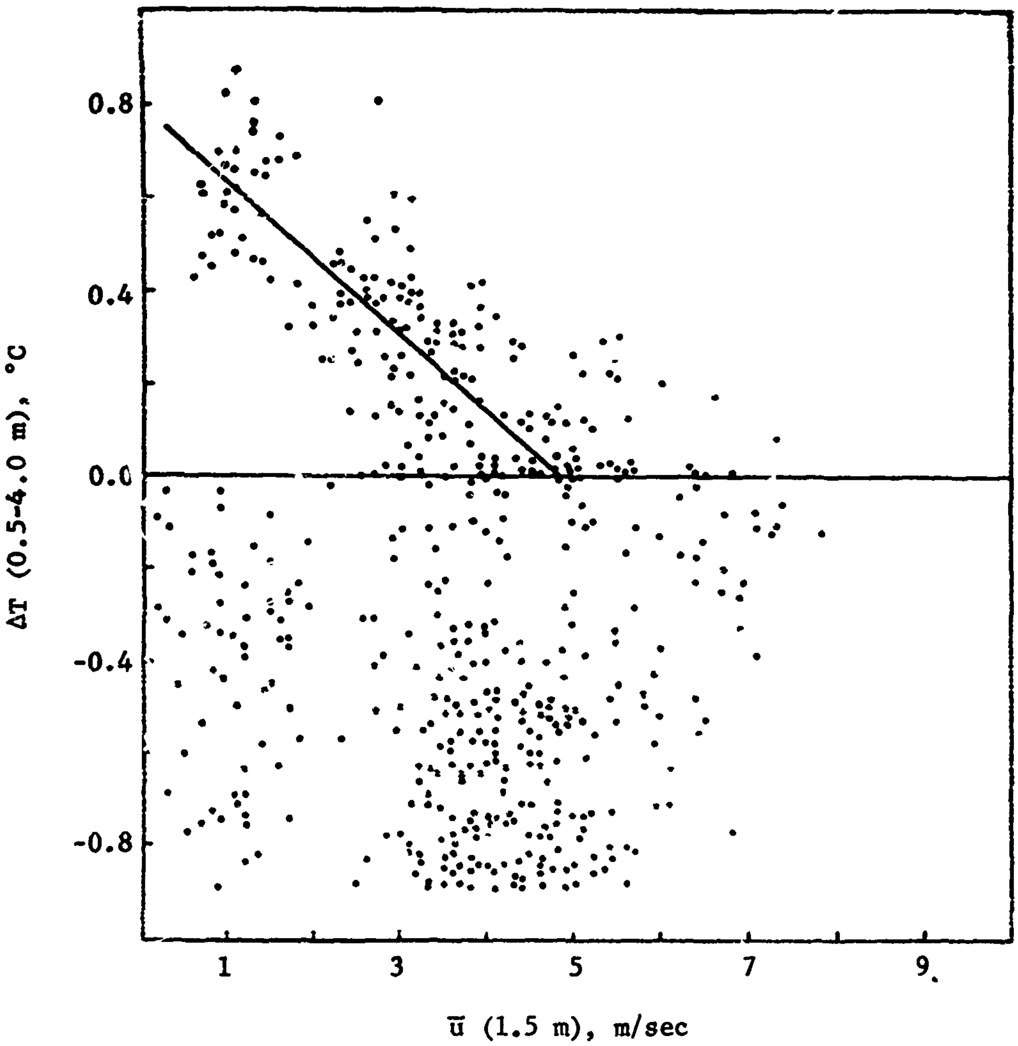

Figure 8(a). GRAPHICAL RELATIONSHIPS BETWEEN ΔT AND $\overline{u}(1.5\ m)$.

(1.5 - 4.0 meters) when $\Delta T > -0.25C$, but when $\Delta T < -0.25C$, the magnitude of the σ's generally becomes smaller as ΔT becomes more negative. z/L also decreases as the σ's increase for values of $z/L > -0.02$, but for smaller values of z/L no general relationship appears to hold. The standard deviation of wind direction (σ_A) is not related to ΔT or z/L.

B. For the Layer 4.0 - 16.0 Meters

Standard deviations of the lateral component (σ_V) and wind direction (σ_A) are not related to ΔT or z/L for any range of values. The standard deviations of the longitudinal and vertical components (σ_u and σ_w) increase with a decrease in ΔT (4.0 - 16.0 meters) for $\Delta T > -0.25C$, but when $\Delta T < -0.25C$, the magnitude of the σ's either remains constant or becomes smaller as ΔT becomes more negative. At the top of the layer (16.0 meters), σ_u and σ_w tend to increase with a decrease in ΔT although the relationship is poor.

C. Wind Speed vs Stability

The wind speed increases as the degree of static stability decreases, but only during stable conditions. During unstable conditions (decrease of temperature with height), the wind speed may vary from 1-8 m/sec and is independent of the degree of instability.

D. Relationship Between z/L and ΔT

z/L increases as ΔT increases in near-neutral conditions, but the relationship diminishes when the degree of stability is large or small.

E. Stability vs Diffusion Rates

If we assume that the rate of diffusion is determined by the intensity of turbulence (fluctuations about the mean), ΔT measured through a shallow layer near the ground is not a good indicator of diffusion rates, particularly when the atmosphere is statically unstable (ΔT negative). z/L does not appear to be a significantly better indicator than ΔT during highly unstable conditions.

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